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RESEARCH MEMORANDUM

EFFECTS OF COMBINATIONS OF ASPECT RATIO AND SWEEPBACK AT HIGH SUBSONIC MACH NUMBERS

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

EFFECTS OF COMBINATIONS OF ASPECT RATIO AND SWEEPBACK AT HIGH SUBSONIC MACH NUMBERS

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SUMMARY

An investigation has been conducted in the Langley 24-inch high-speed tunnel to determine the effects of sweepback and low aspect ratio on the aerodynamic characteristics of a wing at high subsonic Mach numbers. Tests were conducted on a 2-inch-chord airfoil of NACA 65-110 section normal to the leading edge at aspect ratios of 2, 3, and 5 and sweepback angles of 0°, 30°, and 45°. Section characteristics were also determined. Mach numbers ranged from 0.40 up to choking, which varied from 0.870 to above 0.960.

It was found that sweepback and low aspect ratio each tend to both delay and lessen the effects of compressibility. When in combination, the effects are cumulative but less than additive. The larger the amount of either variable used in a combination the less will be the effect of the other variable, and, therefore, the greater will be the departure from an additive effect.

INTRODUCTION

The marked increase in drag and erratic stability changes which take place as the critical Mach number is exceeded have been a serious obstacle to transonic flight for quite some time. As has been shown previously in reference 1, the use of low aspect ratios leads to the alleviation of these adverse effects. A simple theory for the infinitely long sweptback wing (reference 2) predicts that only the component of flow perpendicular to the leading edge has significance. The critical Mach number will therefore rise inversely as the cosine of the angle of sweepback. Experimental investigations have been conducted which verify this theory (reference 3). To obtain data at high subsonic speeds showing the combined effect of aspect ratio and sweepback, tests were conducted in the Langley 24-inch high-speed tunnel on a 2-inch-chord airfoil of NACA 65-110 section normal to the leading edge. The investigation included tests of wings at aspect ratios of 2, 3, and 5, and sweepback angles of 0°, 30°, and 45°, and also a determination of section characteristics. Mach numbers ranged from 0.4 up to choking, which varied from 0.870 to above 0.960.

SYMBOLS

c	wing chord, measured perpendicular to leading edge
b	wing span, measured perpendicular to free stream
S	wing area
A	aspect ratio (b^2/S)
Λ	angle of sweepback, degrees
M	free-stream Mach number
C_L	wing lift coefficient
C_D	wing drag coefficient
$C_{M_{c/4}}$	wing pitching-moment coefficient about wing root quarter chord
α	angle of attack, degrees; measured in plane of undisturbed flow

APPARATUS AND TESTS

The Langley 24-inch high-speed tunnel in which these tests were run (reference 4) is a nonreturn, induction-type, tunnel with the induction nozzle placed downstream from the test section. Previous to these tests the tunnel was modified by the installation of flats which reduce the test section width from 24 inches to 18 inches.

Tests were conducted on a 2-inch-chord airfoil of NACA 65-110 section normal to the leading edge at aspect ratios of 2, 3, and 5 and sweepback angles of 0°, 30°, and 45°. Section characteristics were also determined. The infinite aspect ratio tests were made with the model completely spanning the tunnel at zero sweepback.

The finite aspect ratio, zero sweepback models were obtained by successively cutting off the model tips parallel to the free stream. (See figs. 1(a) and 1(c).) For the sweptback tests the model was rotated rearward around the root section quarter chord and the tips were cut off parallel to the free-stream flow. (See fig. 1(b).) In all configurations tested the model passed through end plates flush mounted in the flat walls of the test section. These end plates had holes in them the same shape as the airfoil but slightly larger to permit clearance. Two semispan models were used in order to double the magnitude of the forces thus reducing the scatter in the data by approximately one-half.

Lift, drag, and pitching moment were measured over and angle-of-attack range of -2° to 6° at aspect ratios of 2, 3, and 5 and sweepback angles of 0°, 30°, and 45°. Section characteristics were obtained over the same angle-of-attack range. The Mach number range extended from 0.4 to 0.96, corresponding to Reynolds numbers of 5.3×10^5 to 7.6×10^5.

PRECISION

Small errors in the data result from inaccuracies in the calibration of the balances and the static-pressure orifices and from limitations on the maximum sensitivity of the balance. Since the absolute inaccuracies of the balance are fixed, the errors become larger as the aspect ratio, sweepback, or Mach number decreases. At a Mach number of 0.50, an aspect ratio of 2, and zero sweepback which is the configuration giving least accuracy, the errors in coefficient are of the following order:

$$C_L = \pm 0.008$$

$$C_D = \pm 0.0010$$

$$C_{M_{c/4}} = \pm 0.010$$

$$\alpha = \pm 0.1^{\circ}$$

Tunnel-wall static-pressure surveys, made for representative configurations from 80 percent chord ahead of the leading edge to 155 percent chord behind the trailing edge, showed static-pressure gradients in all cases less than 2 percent up to the choked condition. For this reason it is felt that all data up to but not including the choked Mach number are very nearly the same as free-stream data. The end points of the curves shown in figures 3 and 4 indicate the choked Mach numbers for all configurations tested. At an aspect ratio of 5 and zero sweepback, tests duplicated with only one model in the tunnel showed excellent agreement on all forces.

The type of end-plate arrangement previously discussed was used for all configurations in the test program, the gap being varied in direct proportion to the area of the model tested. Since this resulted in leakage errors which were of the same relative magnitude for all configurations tested, no corrections were applied.

RESULTS AND DISCUSSION

The data are shown in figures 2 to 6. Figure 2 shows wing lift coefficient plotted against angle of attack for various angles of sweepback, Mach numbers, and aspect ratios. Figure 3 shows lift coefficient plotted against Mach number for all aspect ratios and angles of sweepback, starting with a low-speed value of 0.20 for all configurations and holding the respective angles of attack constant as the Mach number was increased. The usual initial rise in lift-curve slope with increasing Mach number is evident in all of the curves. As the Mach number is increased further, the lift in general reaches a peak and the force break occurs. The force break Mach number increases, and the magnitude of the initial rise, the height of the peak, and the rate of loss of lift beyond the peak all become less as the angle of sweepback is increased or the aspect ratio is reduced. For example, the lift at an aspect ratio of 5 and zero sweepback rises with Mach number up to 0.80 and then breaks sharply downward until at a Mach number of 0.925 it has fallen well below the low-speed value. When the same aspect ratio is used at 30° of sweepback, the lift does not rise as rapidly and does not attain as high a peak, but at a Mach number of 0.925 is still better than at low speed. As an extreme case, consider the lift coefficients at an aspect ratio of 2 or 3 and 45° of sweepback which rise very slowly with Mach number up to a Mach number of above 0.925. Thus, within the range of this investigation, use of sweepback or low aspect ratio tend to both delay and reduce the effects of compressibility. When in combination, the effects of sweepback and low aspect ratio are cumulative but less than additive. The larger the amount of either variable used in a combination, the less will be the effect of the other variable and, therefore, the greater will be the departure from an additive effect.

Figure 4 shows drag coefficient at zero degrees angle of attack plotted against Mach number for various angles of sweepback and aspect ratios. An effect similar to that for the lift characteristics is noted here, namely, that the use of sweepback or low aspect ratio tends to delay the effects of compressibility. As the sweepback increases and the aspect ratio decreases the drag rise is delayed to a higher Mach number and occurs less abruptly. When sweepback and low aspect ratio are combined, their effects become cumulative but less than additive. The larger the amount of either variable used in a combination, the greater will be the departure from an additive effect. Comparing the three parts of figure 4 shows this later effect markedly. As the aspect ratio decreases the changes in drag coefficient at high Mach numbers due to changes in sweepback become less and, similarly, as the sweepback increases, changes in drag coefficient due to changes in aspect ratio become less. Decreasing the aspect ratio at constant sweepback tends to increase the low-speed drag coefficient due to both the increase in induced drag and also because the ratio of tip drag to total drag increases with decreasing aspect ratio. However, sweeping the wing back at constant aspect ratio tends to decrease the low-speed drag coefficient slightly.

The lift and drag data have been plotted together in the form of polars in figure 5. Examination of these curves indicates that the same conclusions can be drawn at all values of lift coefficient as have been drawn in the preceding discussion.

The pitching-moment coefficient about the root section quarter chord is shown in figure 6 as a function of lift coefficient for various Mach numbers, angles of sweepback, and aspect ratios. The negative pitching-moment coefficient of the infinite aspect ratio wing and unswept wing of aspect ratio equal to 5 increases slightly with increasing Mach number. However, compressibility seems to have little effect on the swept-back or lower-aspect-ratio wings. As the wing is swept back, the negative pitching moment increases markedly, as shown in figure 6. This rearward shift of the center of pressure is what would be expected from a consideration of the geometry of the various configurations. Changes in aspect ratio do not greatly affect the pitching-moment coefficient at zero sweep, but in the case of a sweptback wing, lowering the aspect ratio reduces the rearward shift of the center of pressure and therefore causes a decrease in the negative pitching-moment coefficient about the root section.

The lift and drag data already shown would seem to indicate that sweepback is more effective than low aspect ratio in reducing the effects of compressibility. It should be remembered, however, that these data are for similar wings of constant thickness-to-chord ratio and are therefore not representative of a design problem involving choice of wing plan form for a given airplane. In a given design problem, the thickness-to-chord ratio of the wing section may be varied and, therefore, use of low aspect ratio will generally permit the use of a thinner section, thus dissipating, to a larger extent, the apparent superiority of sweepback over low aspect ratio shown by these data. Consider, for example, two wings having the same wing loading and operating at the same Mach number, one with an aspect ratio of 5 and 30° of sweepback, the other with an aspect ratio of 2 and 0° sweepback. Due to the smaller span, the greater chord for equal areas, and the absence of high negative pitching moments about the root section, the thickness-to-chord ratio of the low-aspect-ratio wing could be an estimated 60 to 70 percent lower than that of the sweptback wing. The critical Mach number of such a wing would therefore be raised to a considerably higher value. This point should be carefully considered in the choice of a suitable wing plan form for high subsonic Mach numbers.

CONCLUDING REMARKS

An investigation of wings with various combinations of aspect ratio and sweepback at high subsonic Mach numbers has shown that sweepback and low aspect ratio each tend to both delay and lessen the effects of compressibility. Further, that when in combination, the effects of sweepback and low aspect ratio tend to be cumulative but less than additive. The larger the amount of either variable used in a combination, the less will be the effect of the other variable and, therefore, the greater will be the departure from an additive effect.

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3. Koch, G.: Druckverteilungsmessungen am schiebenden Tragflügel. Bericht 156 der Lilienthal-Gesellschaft, 1942, pp. 41-47.

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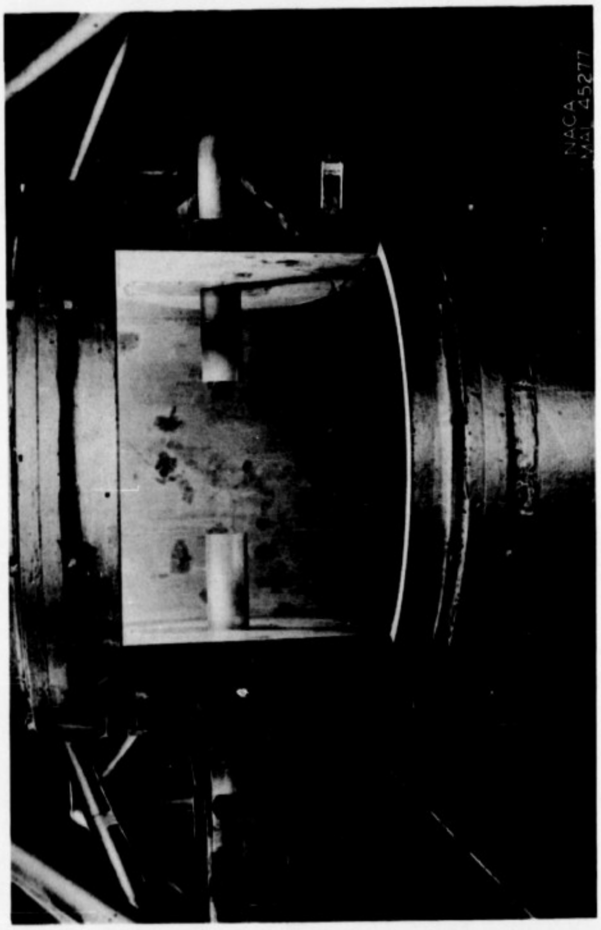

(a) Over-all view with access door removed showing model installation. A = 5; Λ = 0°.

Figure 1.- Model mounted in test section of Langley 24-inch high-speed tunnel.

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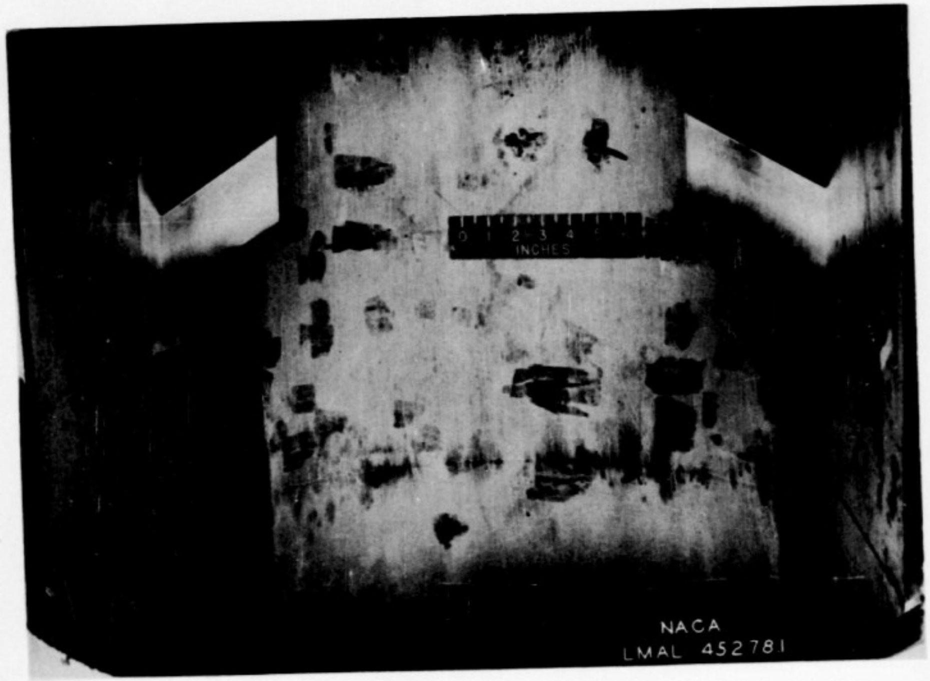

(b) Close-up showing interior of test section with model in place. $A = 3$; $\Lambda = 30^{\circ}$.

Figure 1.- Continued.

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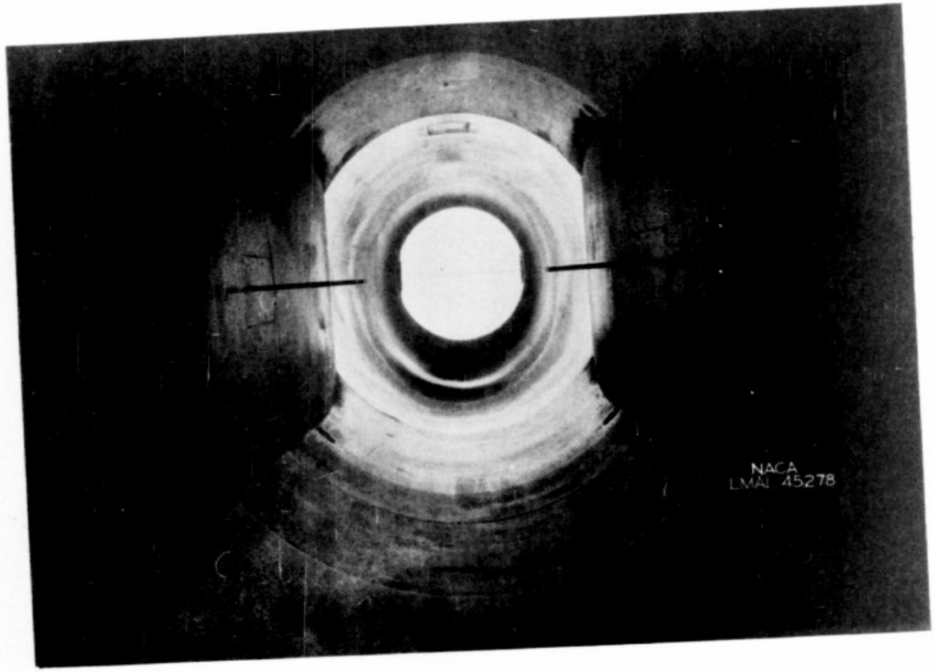

(c) Downstream view with model in place. $A = 5$; $\Lambda = 0^{\circ}$.

Figure 1.- Concluded.

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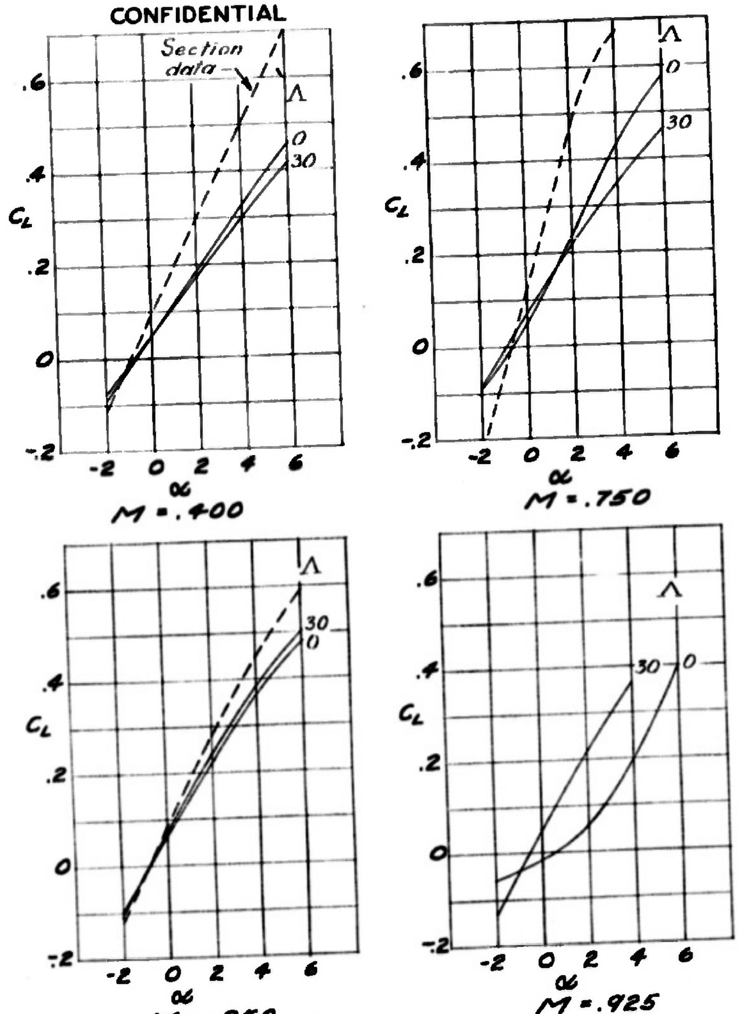

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(a) A = 5.

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Figure 2.– Effect of sweepback and aspect ratio on the lift of a wing over a range of Mach numbers.

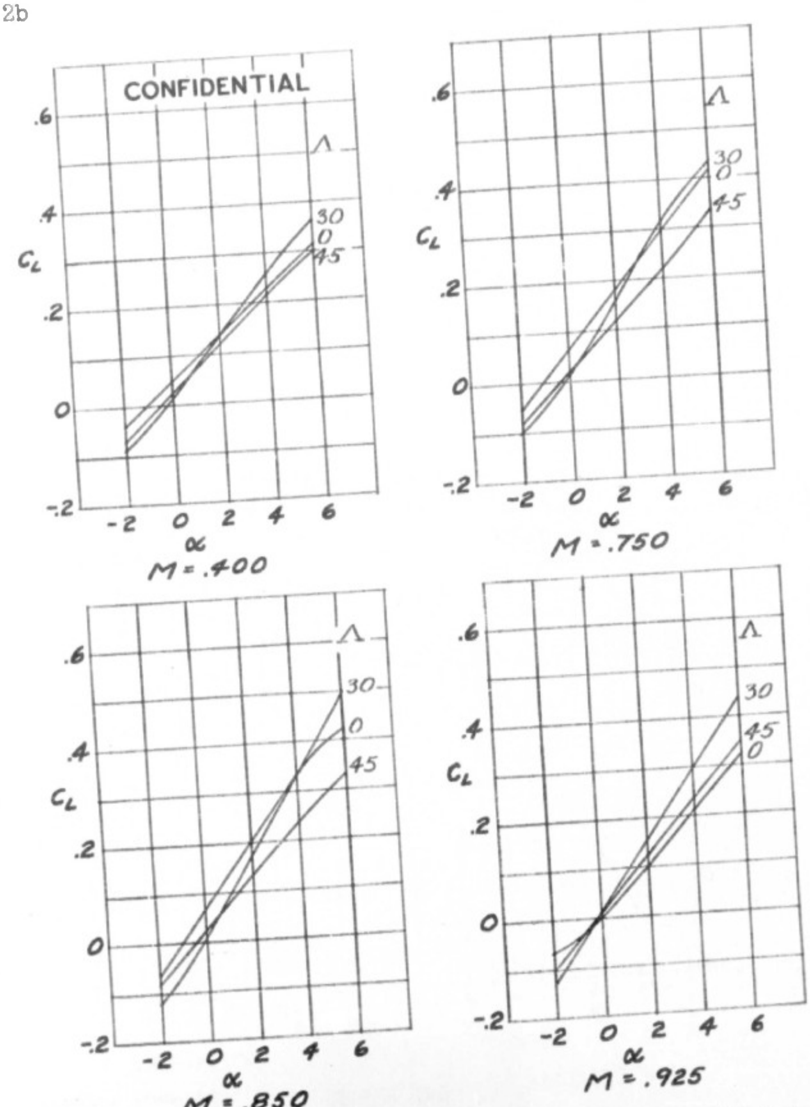

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Figure 2.- Continued.

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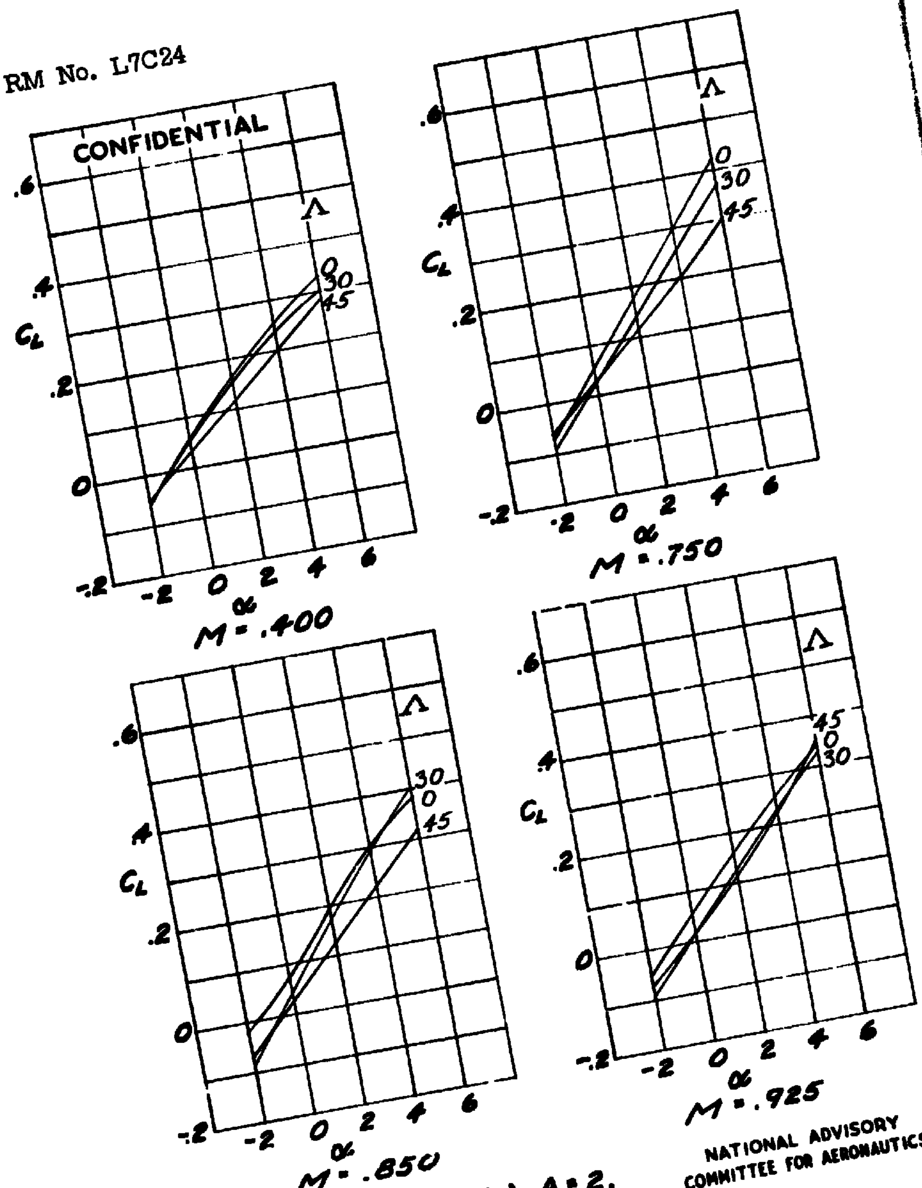

(c) A = 2.

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Figure 2. - Concluded.

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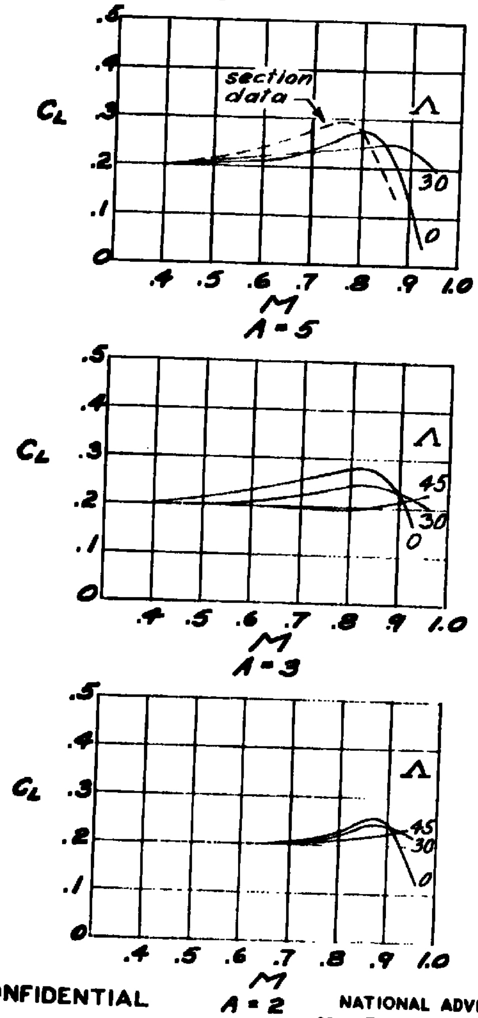

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Figure 3. - Effect of compressibility on the lift coefficient of a wing with various aspect ratios and angles of sweepback.

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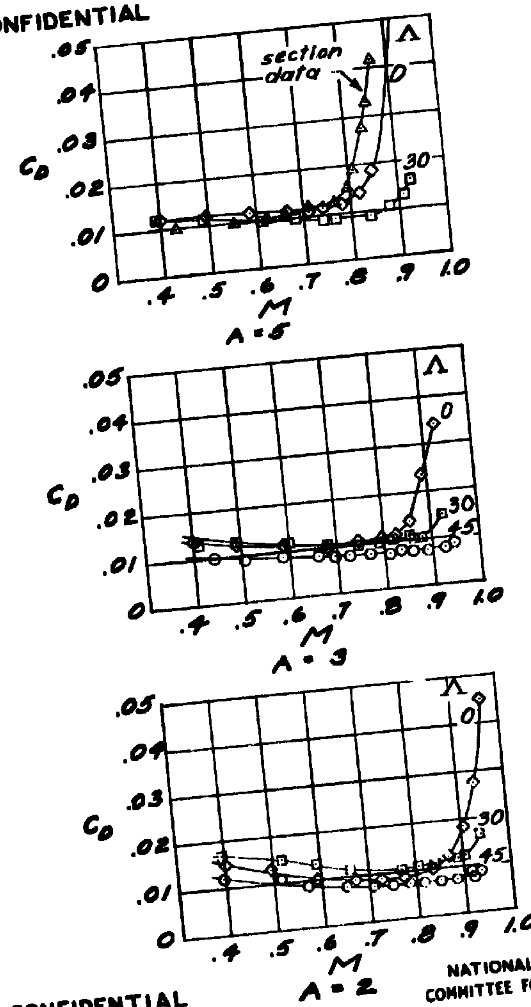

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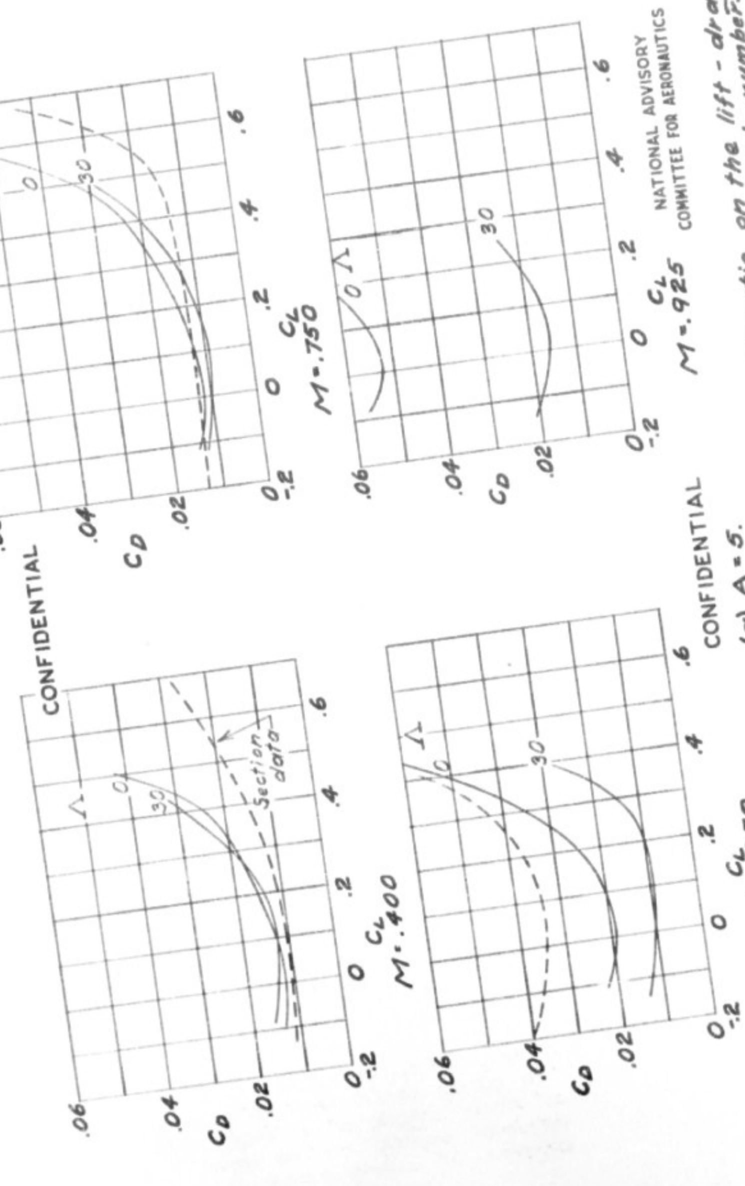
Figure 4. - Effect of compressibility on the drag coefficient of a wing at zero angle of attack with various aspect ratios and angles of sweepback.



(a) A = 5.

Figure 5.- Effect of sweepback and aspect ratio on the lift-drag characteristics of a wing over a range of Mach numbers.

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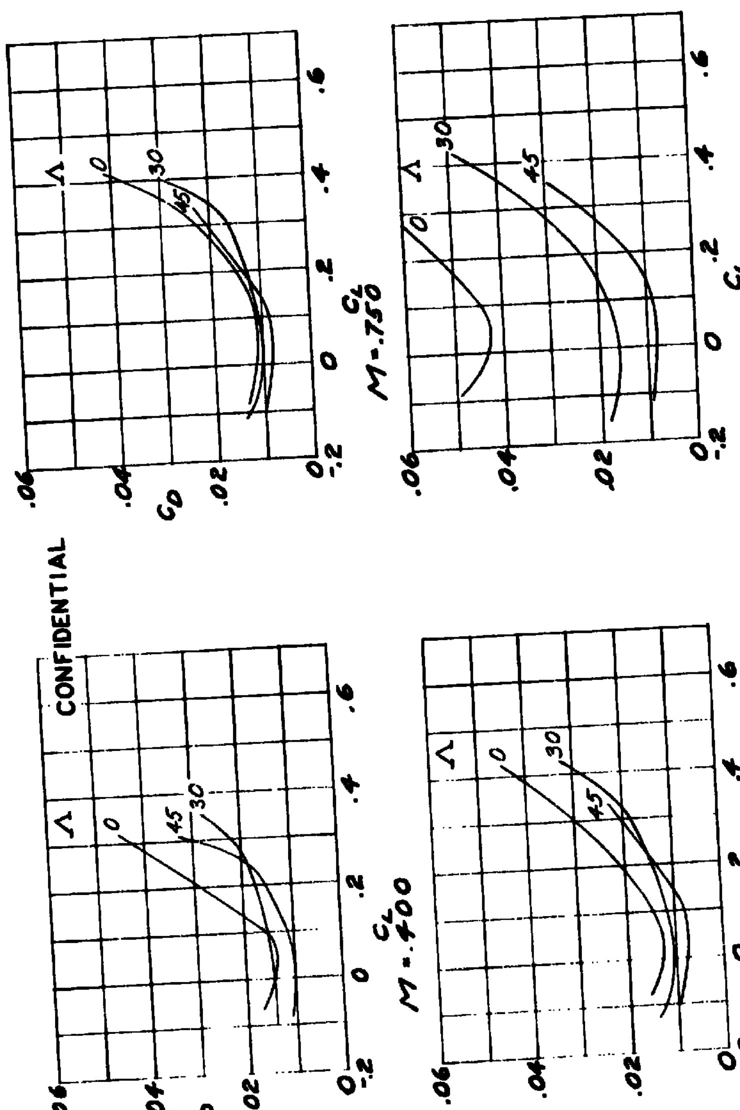

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(b) A = 3.

Figure 5. - Continued.

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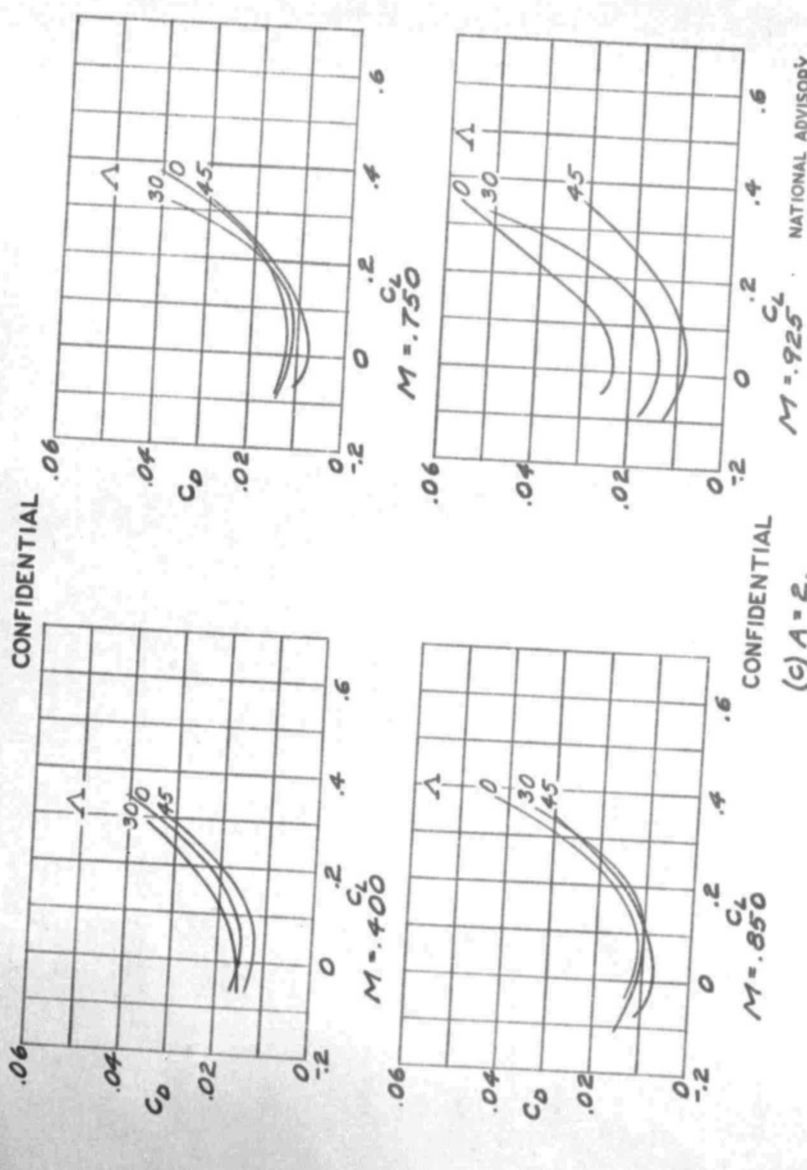

(c) A = 2.

Figure 5. - Concluded.

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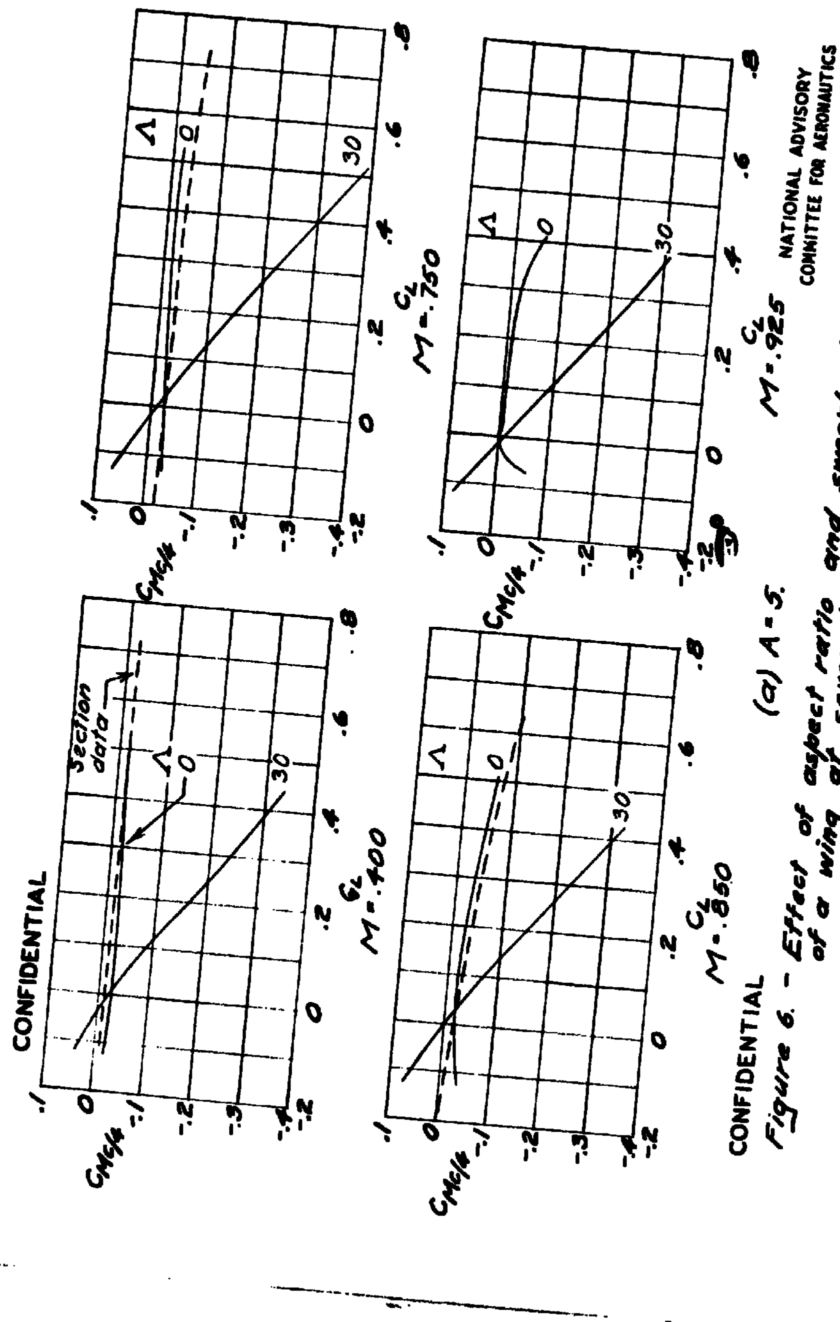

(a) A = 5.

Figure 6. - Effect of aspect ratio and sweepback on the stability of a wing at several Mach numbers.

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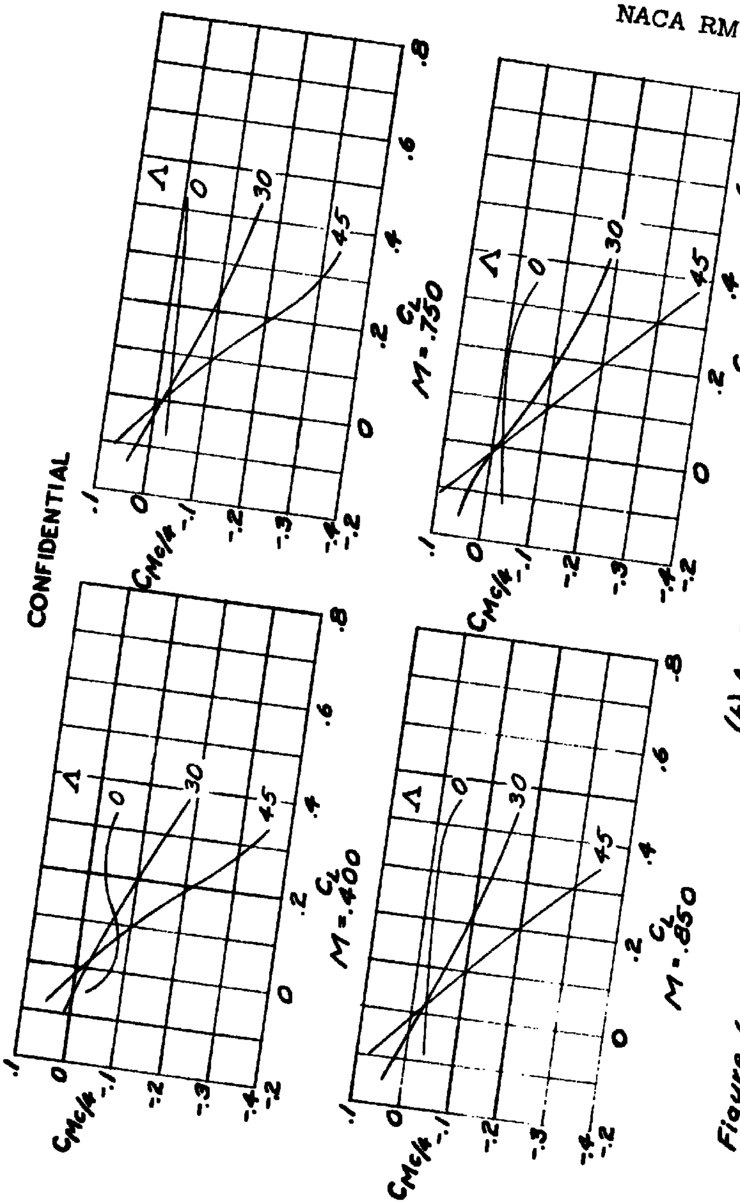

(b) A = 3.

Figure 6.- Continued.

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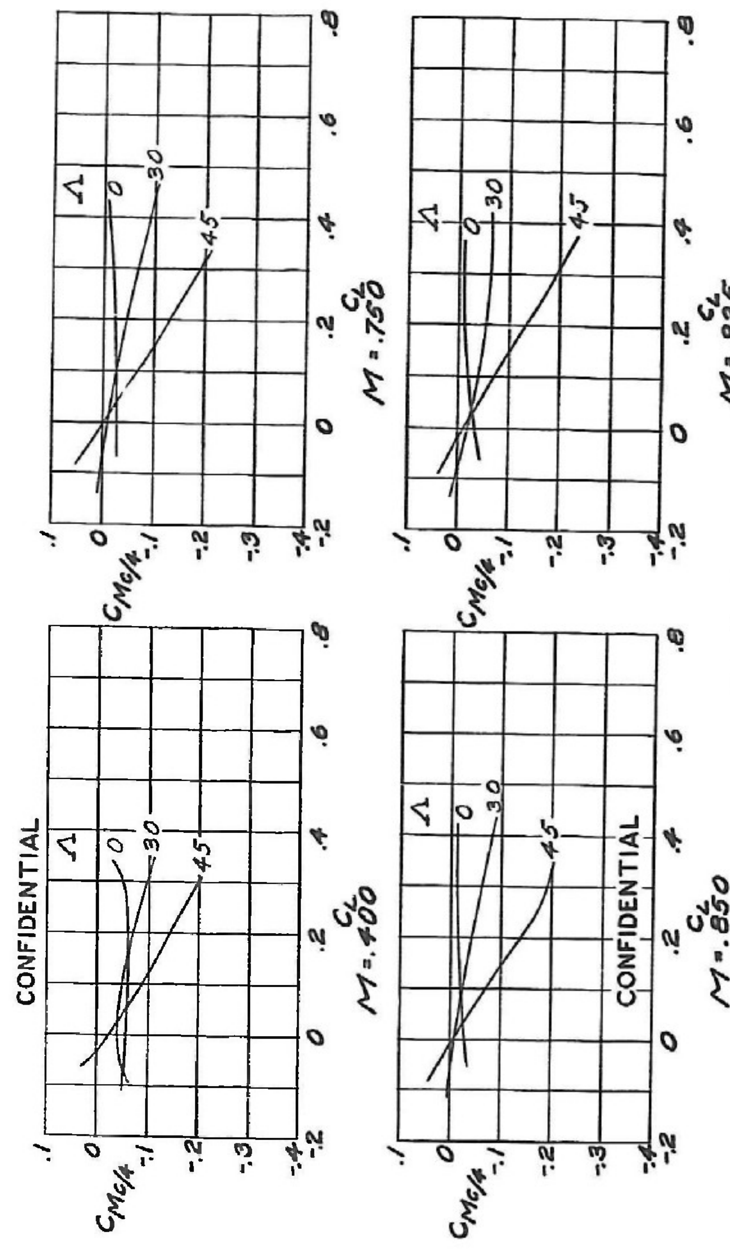

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(c) A = 2.

Figure 6. - Concluded.

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